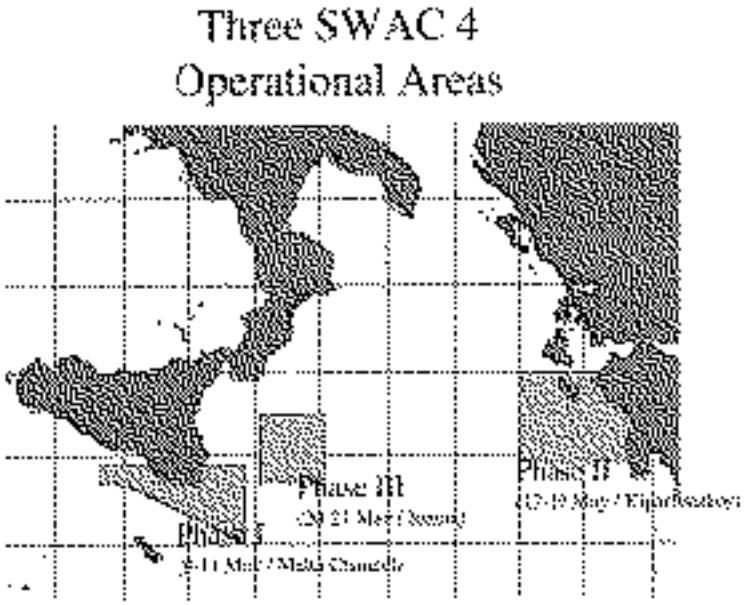
Acoustic Analysis of SWAC 4 Phase II

SACLANTCEN Bioacoustics Panel
June 15-16 1998

Fred McMullen
United States
Naval Undersea Warfare Center
Division Newport. R.I.
Code 3124
Phone: (401) 832-8670
Email: mcmullenfe@npt.nuwc.navy.mil

Elena McCarthy
United States
Naval Undersea Warfare Center
Division Newport. R.I.
Code 3114
Phone: (401) 832- 8684
Email: mccarthyem@npt.nuwc.navy.mil



SWAC 4 Analysis Focus

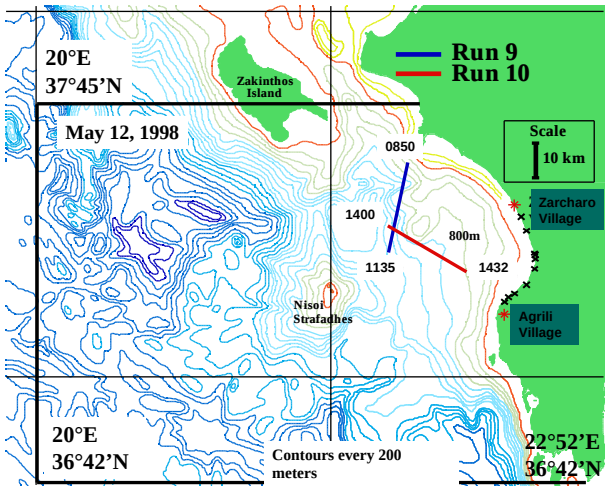
Runs 9 and 10 were chosen based on the estimated time the whales beached[1] (morning to early afternoon of 12 May 1996). Parameters are given in the following table.

Local Time is GMT (Greenwich Mean Time) + 3 hours

Run	Date	Start hh:mm Local	Finish hh:mm Local	NRV Alliance Speed(kts)	TVDS Depth(m)	MFTA Depth(m)	LFTA Depth(m)	Total Pings
Run 9	May 12	08:30	11:56	5	82-72	76-69	77 -86	208
Run 10	May 12	14:00	16:33	5	72	69	77-83	157

(1) Scientific Correspondence: “Does Acoustic Testing Strand Whales?,” A. Frantzis, Nature (magazine), 5 March 1998.

SWAC 4 Events Examined



locations from: "Mass Stranding of Ziphius cavirostris in Greece," 12 May 1996. http:/whales.magna.com.au/News/Ziphius.html

SWAC 4 Acoustic Analysis

- Objective:
  Acoustically detect the presence of marine mammals in Runs 9 and 10 of the SWAC-4 sea test.
- Conclusion:
  Marine mammals have not been detected passively or actively in the acoustic data analyzed.

Cuvier Beaked Whale Characteristics

- Estimate Cuvier's Beaked Whale target strength
- Estimate Cuvier's Beaked Whale vocalization frequency and source level
- Compute signal excess and identify ocean regions where detection of the marine mammal might be possible

Resonant Frequency Analysis

- Model Types Used
  1). Minnaert's theory - resonance of gas filled sphere in a fluid:
  $f_{res} = \frac{660 * SQRT(pressure)}{\text{Lung diameter}}$
  2). Resonant Air Bubble:
  $f_{res} = (1/2\pi) * SQRT[(3\gamma p + 4u)/roh]$
- Assumptions
  1). Lungs are primary resonators.
  2). Lung volume of the Cuvier's Beaked whale can be scaled down linearly from humpback whale.
  3). Shear modulus of whale flesh is equal to fish flesh.

Refs: Minnaert, M " On Musical Air Bubbles and the Sounds of Running Water," Phil. Mag., N 16, pp 235-248. (YEAR?)
Barham, E.G., "Whales Respiratory Volume aas a Possible Resonant Receiver for 20 Hz Signals," Nature, Vol. 245, p. 220, 28 September 1973.

Resonant Frequency Analysis Results

DEPTH	RESONANT FREQ (Minnaert)	RESONANT FREQ (Barham)
20 m	25.9 Hz	28.9 Hz
74 m	58 Hz	63 Hz
500 m	291 Hz	289 Hz

- Assumes a lung volume at the surface of 136 liters.
- Resonant frequency depends largely on lung volume which is depth dependent.

Active Sonar Equation Analysis

We have begun examining the terms of the active sonar equation. In the TVDS presentation, we looked at source level (SL) and in the Oceanographic presentation we examined transmission loss (TL). Next, an estimate of the target strength term will be conducted.

A version which governs active, matched filter, beam detections is:

$$SE = SL - TL_1 + TS - TL_2 + PG - DT - [(NL - AG) + RL]$$

system terms | signal mask terms

Marine Mammal Lung Capacity and Relative Sizes

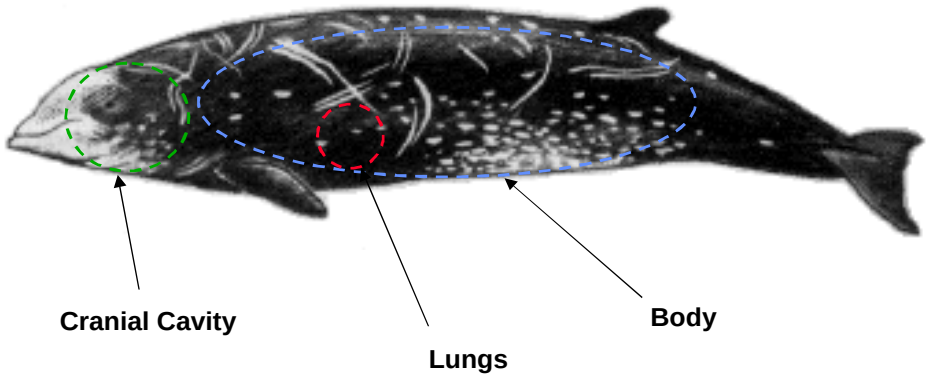
Finback Whale *(Balainoptera physalus)*
L = 21.6 m
W = 73,000 kg
Measured Lung Volume = 2,000 litres

Cuvier's Beaked Whale *(Ziphius cavirostris)*
L = 5 - 6 m
W = 5300 kg
Calculated Lung Volume = 136 litres

Bottlenose Dolphin *(Tursiops truncatus)*
L = 2.2 m
W = 126 kg
Measured Lung Volume = 3 - 3.5 litres

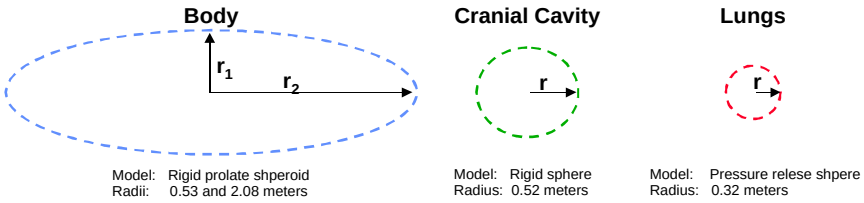
Estimated Cuvier's Beaked Whale Target Strength

Model Shapes and Locations



Estimated Cuvier's Beaked Whale Target Strength

- Simplistic target strength model developed by:
  - Scaling the Humpback Whale and Atlantic Bottlenose Dolphin to match Cuvier's Beaked Whale
  - Assuming head and body are rigid, perfectly reflecting spheroids
  - Modeling blubber as anechoic covering



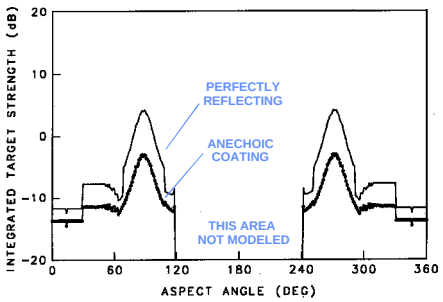
Model: Rigid prolate shperoid
Radii: 0.53 and 2.08 meters

Model: Rigid sphere
Radius: 0.52 meters

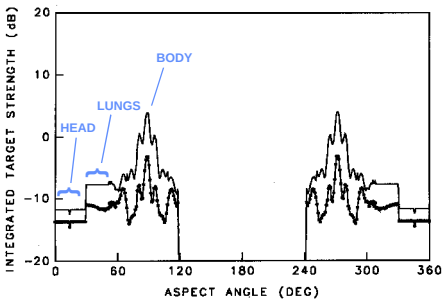
Model: Pressure relese shpere
Radius: 0.32 meters

Estimated Cuvier's Beaked Whale Target Strength

Target Strength for LF



Target Strength for MF



Estimated Target Strength varies between -13 and +4 dB as a function of aspect.

Active Sonar Equation Analysis

An estimate of the expected MF active signal excess (SE) was made. As a result of this estimate (see following) the search was focused to those areas where one way propagation loss was expected to be less than 78 dB.

* * * *

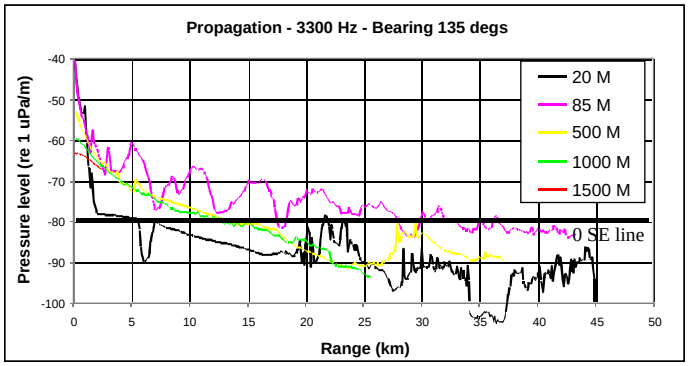
Reviewing the active sonar equation we have:

$$SE = SL - TL_1 + TS - TL_2 + PG - DT - [(NL - AG) + RL]$$

$$SE_{3300} = 223 - TL_1 + 0 - TL_2 + 13 - 10 - [70]$$
$$SE_{3300} = 156 - 2(TL)$$

Substituting the appropriate values, we find that a one way loss of 78 dB re 1 µPa gives 0 dB signal excess.

SWAC 4 Mid Frequency Propagation Loss at Five Depths



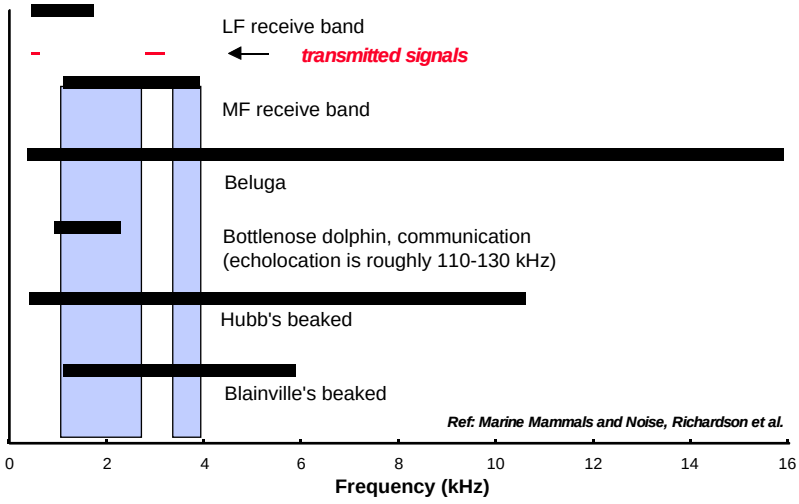
Cuvier's Beaked Whale Vocalization Analysis

- Conducted background review of beaked whales to identify vocalization frequency band and to locate recordings of chirps, clicks, and whistles.
- Using the references below, estimated vocalizations can occur across a wide frequency band 300 Hz to 40 kHz
  - Received recordings made of a baby Hubb's Beaked Whale (Mesoplodon Carlhubbsi) to aid in passive filtering process

Reference: "Pulse Sequence and Whistle Production by Two Captive Beached Whales, Mesoplodon Species", Spencer K. Lynn and Diana L. Reiss, Marine Mammal Science, 8(3):299-305, July 1992.

"Sounds Produced by Two Rare Cetaceans Stranded in Florida", David K. Cldwell and Melba C. Caldwell, Cetology, 4:1-6.

Band Use Relationships

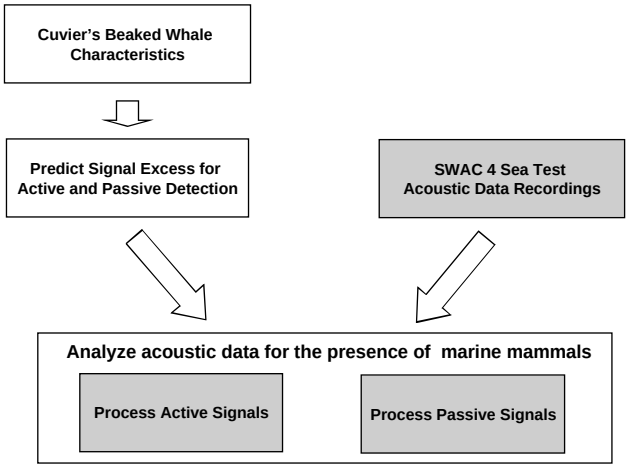


Passive Signal Excess

Plugging in estimated values for a version of the passive sonar equation (which follows), it is estimated that a vocalization level of 160 dB would be needed to combat 80 dB of TL and be detected.

$$SE = SL - TL - (NL - AG) - DT$$

SWAC 4
Analysis Approach



SWAC 4
Acoustic Data Recordings
Inventory at NUWCDIVNPT Code 30

- Given the focus on SWAC 4 Runs 9 and 10 and the processing capability available at NUWC, the following data types were examined
  - Mid frequency towed array receiver hydrophone acoustic data
    - Band-pass filtering for 1 to 4 kHz
    - Sample rate of 12 kHz
  - SACLANTCEN beamformer output data for mid frequency towed array receiver
    - Signal conditioned to a sample rate of 1.333 kHz

SWAC 4
Active Analysis

- Processed runs 9 and 10 mid frequency hyperbolic FM active acoustic data through signal processing algorithms
- Using the active sonar signal excess calculation and transmission loss estimates, analysis was focused on the following areas
  - Short range analysis 0 -10 km defined as region 1 propagation
  - Long range analysis 10 km and greater defined as region 2 propagation

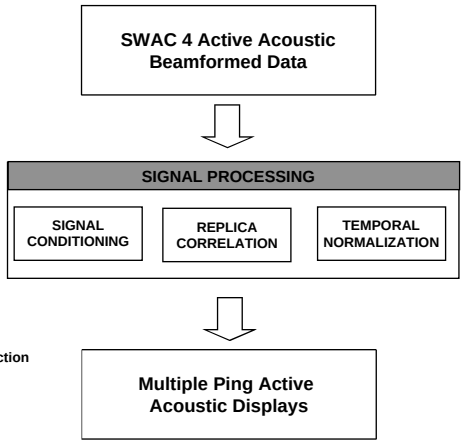
SWAC 4 Active Signal Processing

Acoustic Data
Runs 9 and 10
Mid-Frequency Towed Array
SACLANTCEN Beamformer

Waveform
Hyperbolic FM
Pulse Length = 2 seconds
Bandwidth = 400Hz

Normalization
Set gap to marine mammal length = 5m

Display
Set Display thresholds for low SNR detection



Multiple Ping Acoustic Active Data Displays

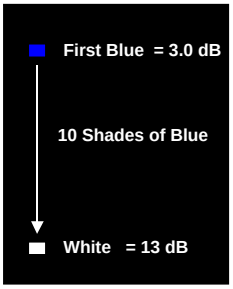
Display:

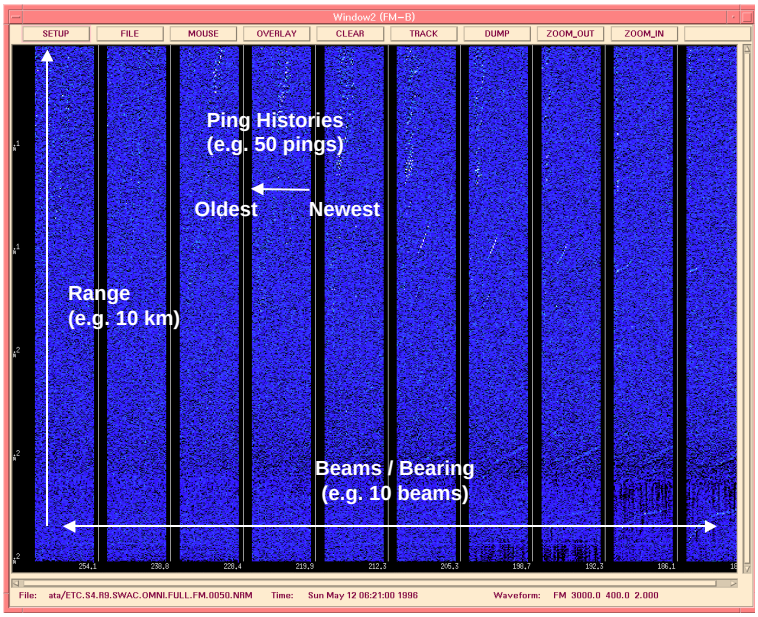
Normalizer amplitude output

No ownship motion compensation

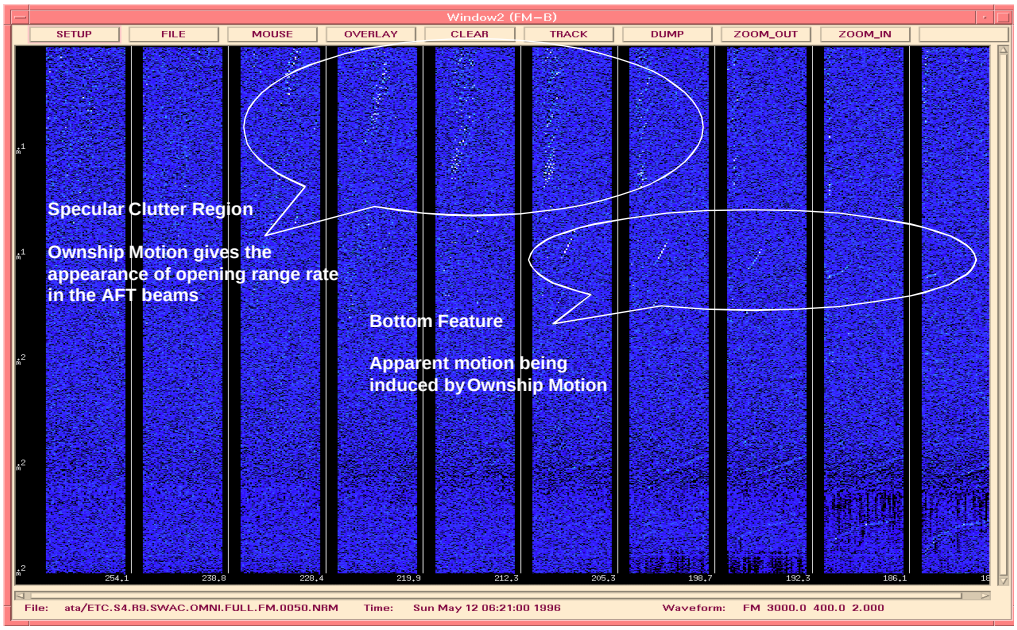
Beam Maximum Response Angles are relative to the Alliance plus a 90 degrees offset

Amplitude to color map below

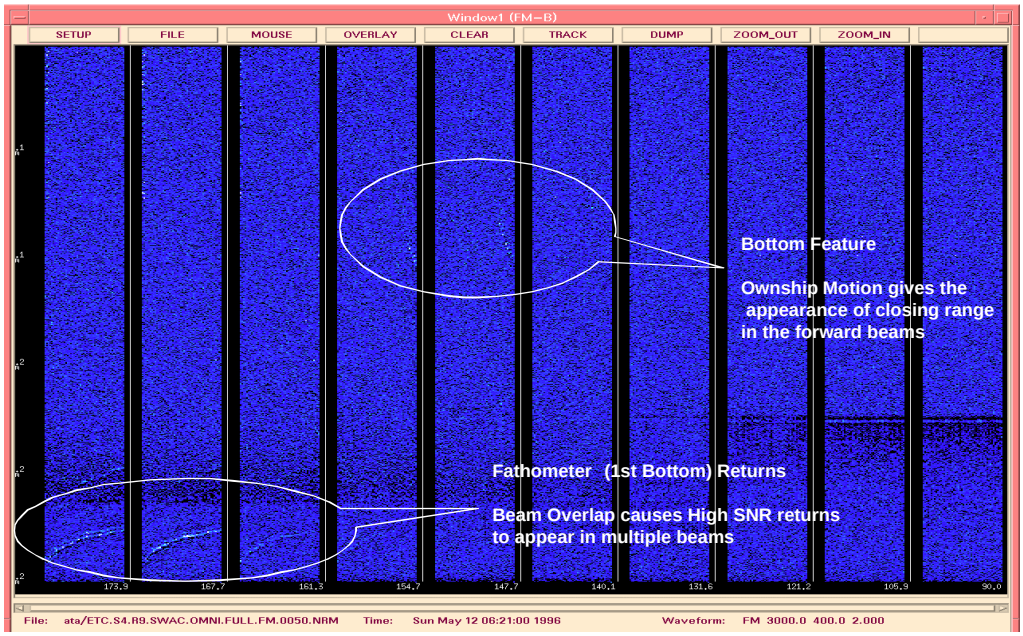




SWAC 4 Run9 Active Data
Aft Beams, 1-50 pings, 0-10 km



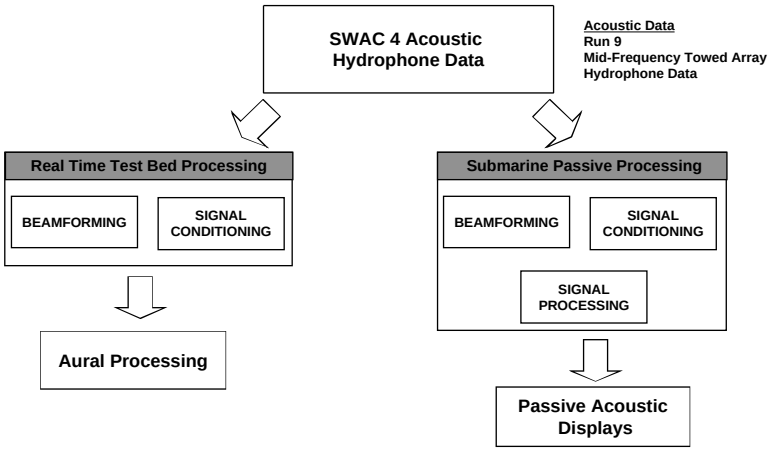
SWAC 4 Run9 Active Data
Fwd Beams, 1-50 pings, 0-10 km



SWAC 4
Active Analysis Summary

- The presence of marine mammals was not detected in runs 9 and 10 of the SWAC 4 sea test using the mid frequency towed array receiver and the hyperbolic FM waveform
- Observed stationary detections were attributed to reverberation effects and objects located on the bottom

SWAC 4 Passive Signal Processing



SWAC4 Passive
Analysis Summary

- Analysis of SWAC 4 run 9 mid frequency towed array hydrophone acoustic data revealed that the data had been corrupted during the duplication process
  - Third most significant bit in the acoustic data is set incorrectly and the ramifications of this error are not fully understood at this time
  - Follow on analysis showed that the mid frequency run 10 data was also corrupted
- Conclusion:

In the very limited SWAC 4 run 9 mid frequency data analyzed, the presence of marine mammals was not detected, however, solid conclusions are suspect due to data contamination